Rapid Compositional Analysis of 61 *Zea mays*
Samples Using Near-infrared Spectroscopy

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Abstract

Rapid Compositional Analysis of 61 *Zea mays* Samples Using Near-infrared Spectroscopy. JONATHAN MEUSER (University of California, Davis, California 95616), STEVEN THOMAS and TAMMY HAYWARD (National Renewable Energy Laboratory, Golden, Colorado, 80401).

A major challenge in commercializing ethanol production from corn stover is the great variability in composition of commonly grown varieties. Only when the variables that determine stover composition are isolated can optimum stover be produced, making possible consistent process yields and economics. The extent to which environmental and genetic factors affect cell wall composition in corn stover is unknown. In this study, the cell-wall composition of 61 stover samples was determined by near-infrared spectroscopy (NIR). With NIR, the composition of many samples can be economically, accurately and quickly determined, providing the bulk of data necessary to perform meaningful statistics. As we approach a high-throughput system of compositional analysis, outlying samples and the variables that cause their dissimilarity may be more readily understood. For instance, though closely related to commercial corn, *Teosinte parviglumis* drastically differed in composition. Also, Pioneer B73xMo17 and Pioneer 33P67 were tested to determine the affect of irrigation, planting density and variety on cell-wall composition. These variables proved to be insignificant factors in composition, however, 33P67 grown under the same conditions had unusual variability in soluble sugars. Because irrigation and planting density commonly differs between fields, eliminating these two variables as factors affecting composition allows greater flexibility in growing and experimentating on high value stover. Further research into the exact cause of *Teosinte*'*s* structural differences may illuminate genetic causes of cell-wall variation for all corn.

Research Category: Biology

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Introduction

Corn stover - the stalk, leaves and cobs of corn - has had few traditional uses, and it is usually burned or turned back into the soil. Contemporary experimentation on stover feedstock for ethanol fuel production has promoted a fresh interest in the composition of corn stover, however. According to the U.S. Department of Energy (DOE), "U.S. farmers plant about 80 million acres of corn each year, with a potential (wasted) stover harvest of some 120 million dry tons." Available corn stover thus represents the most abundant bioenergy feedstock available now. Accordingly, the DOE has set a goal of having nine corn-stover-fed commercial ethanol plants in operation by 2006.

Inconsistent conversion of corn stover to ethanol caused by compositional variation thwarts this goal. Consisting primarily of cellulose, hemicellulose and lignin, commercial corn stover diversity highly affects its performance as a fermentable feedstock. One study suggested the carbohydrate content variation in modern corn stover translates into a minimum ethanol selling price difference of 20 cents/gallon (Thomas et. al. 2001). Likewise, optimization of the production process in both pretreatment and simultaneous saccharification and fermentation (SSF) has been complicated by such variations in stover composition, making it difficult to estimate the cost of production. Identifying the factors that generate quality stover feedstock for ethanol production may benefit farmers and/or seed companies in producing a higher quality stover for ethanol production, making ethanol fuel a cost-effective alternative to fossil fuels.

In this study, we compared the composition of many genetically distinct lines, both commercial and exotic, grown under a range of environmental conditions to explain stover compositional variations.

Materials and Methods

In November 2001, Ken Russell, Assistant Professor at the University of Nebraska, Lincoln, collected residual corn stover, including leaves and stalk, from 44 plots of corn representing 21 varieties from two fields. He dried them to below 20% moisture, and shipped them individually packed by UPS ground delivery to the National Renewable Energy Lab (NREL). On arrival, all samples were air-dried for 3 days at 80°C in the NREL Field Test Laboratory Building greenhouse. All the samples were photographed, indexed for dryness, and given an identification number. The samples were professionally milled 6 months later into a coarsely ground homogenous mixture that passed through a ¼-in. screen. Each milled sample was divided into equivalent 500 g portions and stored in large, labeled plastic bags placed inside plastic buckets, also labeled.

We collected near-infrared (NIR) reflectance spectral data in duplicate using the FOSS NIR Forage spectrometer (FOSS NIRsystems, Inc., Silver Spring, Maryland) and WinISI analytical software. Representative grabs were loaded into a clean natural product cell, compressed against the quartz lens with the sample cell backing, and placed into the NIR spectrometer for analysis.

The percentage of dry weight of 12 corn stover constituents were determined using a model developed at the NREL Biotechnology Center for Fuels and Chemicals. Nothing can be proven by variation below the method error of the model. Because +/-1.5% is the method error of near-infrared prediction based on wet chemical analysis, constituents with a range in percentage of dry weight below 3% were discarded from the statistical analysis. Components with a statistically relevant range of values were glucan (cellulose, hemicellulose, and soluble sugars), xylan (hemicellulose), lignin, protein, and structural inorganics. We derived soluble glucan by subtracting structural glucan from total glucan. Components with confirmable variation were then tested for linear correlation against other constituents. We also tested the effect of irrigation, planting density, and variety on a representative subset of the population, eight samples of 33P67 and eight samples of B73xMO17, using full factorial 2^3 statistical analysis.

In this study, many methods were used to identify outliers in the population. Initially, outliers were identified by global-H and neighborhood-H values representing the closeness of each sample to the family of samples in the model. The standard deviation of values within this sample set was also calculated. Samples with values above or below two standard deviations (95% confidence interval) were noted. To further elucidate outliers of our 61-sample population and isolate components having the greatest effect, we performed the chi-square test on all eight significant constituents. Then, by excluding components from the chi-square test and observing the change in goodness-of-fit, we could determine the component(s) most responsible for a sample's outlying character.

Results

The FOSS NIR spectrometer (see Table 1) was used to predict twelve common corn stover constituents. The range and standard deviation within this data set for each of these constituents are shown in Tables 1 and 2. Only the fractions - total glucan, structural glucan, soluble glucan, lignin, protein, arabinan and structural inorganics - ranged greater than +/-1.5%, the accuracy of the wet chemical methods used to produce the model. Soluble glucan ranged 13.8% (see Table 2). Acetyl, uronic acid, galactan, mannan and soil values ranged less than 3% and were excluded from further analysis.

Additionally, no significant linear correlation of any two of the twelve compositional components could be found.

The standard deviation between duplicates was under 1% for all but one sample, 2868-091. This sample was shipped in two boxes and milled separately, labeled 2a and 2b. These separate boxes of sample 2868-091 had a 3% variation in total glucan, 18% in xylan and 20% difference in lignin. However, duplicate grabs from 2a and 2b respectively yielded an expected standard deviation below 1% (see Table 3).

Of 61 samples, none had global-H or neighborhood-H values above the maximum of 3. However, the nine samples of 33P67 from field two had outlying neighborhood H values above one (Table 1). Average mass closure for all samples was 97.39%.

Full factorial 2^3 analysis showed that irrigation, planting density, and variety had no effect on the variation of relevant constituents in Pioneer varieties Mo17xB73 and 33P67. (Table 4). The error of the method is +/-1.5% dry matter, so any effect less than 3% could not be considered significant. Soil-free and soil-and-structural-inorganic-free analysis yielded similar non-significant results.

Of the exotic varieties, *Teosinte parviglumis* (Plot 17) showed the most striking difference in composition (see Figures 1 and 2). *T. parviglumis* had total glucan and soluble glucan (Table 1) levels more than two standard deviations above the population mean, high protein levels, a xylan fraction more than two standard deviations below the mean, and significantly lower lignin. Chi-square analysis for all eight significantly varying constituents (more than 3%) produced a value of 0.002. The same analysis omitting total glucan (i.e., soluble sugars) yielded a value of 0.20 when all other chi-square values were raised to over 0.90 without soluble sugar (see Table 5). The neighbor-H average of the *Teosinte* was 0.8; the global-H was 1.2. All the other exotics tested, including *Teosinte* crosses, showed no significant difference in composition.

Discussion and Conclusions

In this study, the components that varied the most - total glucan, structural glucan, and soluble sugars - may play the greatest role in conversion economics. While total and structural glucan represent cellulosic material to be degraded first into sugar and then to ethanol, soluble sugars may represent “free” sugar, in that pretreatment and saccharification are not needed to make these soluble sugars available for fermentation. It may even be possible to wash these sugars from the corn stover for the production of enzyme needed for simultaneous sacharification and fermentation (SSF). For these reasons, identifying what causes or prevents high levels of soluble sugars could play an important role in optimizing ethanol production from corn stover.

From this data set, two examples showed abnormally high levels of soluble sugars. In field one, Pioneer 33P67 has soluble sugar levels around 7%. However, for some unknown reason, soluble sugar levels about twice as high were found in field two for the same variety under very similar growing conditions (see Figure 1). It seems likely that harvest variation might cause such a difference. As corn finishes its annual life cycle it probably metabolizes most available sugars in the process of dying. However, stover harvested near the time of grain harvest, while still green, its phloem still rich in photosynthetically produced soluble sugars, would likely still contain these sugars preserved in the drying oven. Further investigation is recommended to test the effect of post-harvest standing time in the field and time till drying after harvest on total glucan and soluble sugar content. Other factors, such as rain on exposed stover that may wash away sugars, may play a role in lowering soluble sugar content.

There are many possible explanations of the disparity in composition between Plot 2A and 2B (see Table 3). Corn stover varies in composition by anatomical fraction. Shipped and milled separately, these divisions of the same plot may have been divided unequally, possibly a different ratio of anatomical fractions occurring in each box. Though, until more information is obtained from Ken Russell on this plot and other unknowns between fields one and two, there is no absolute explanation for the disparity in composition between Plot 2A and 2B.

In the case of *T. parviglumis*, speculation could be made to the contrary. Chi-square analysis of Pioneer 33P67 on a soluble-sugar-free basis showed that its other constituents are normal, whereas, the same analysis shows that *T. parviglumis* has a statistically distinct composition with greater difference than simply in high soluble sugars (see Table 5). With about 10% more soluble sugar available for fermentation that the other samples and significantly lower lignin a greater understanding of the cell-wall structure of *T. parviglumis* could aid in breeding a better stover. Through phloroglucinal staining of lignin rich xylem tissue in the vasculature, we might be able to visualize lower lignin levels. Additionally, because other crossed lines of Teosinte and commercial corn parentage showed normal composition, the testing of individual plants and the selfing of these crosses may segregate recessive traits that raise glucan or lower lignin levels. Other variables to consider are anatomical differences such as nodal length and ontogenetic stage in development at the time of harvest. *T. parviglumis.* was harvested after the same number of days as the other plots in the study but may have been at a different developmental stage

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Tables

TABLE 1. University of Nebraska Corn Stover Compositional Data (61 Samples)

Color Key

Above Two Standard Deviations	Neighbor-H > 1.0
Near Two Standard Deviations High	Field One Plots
Near Two Standard Deviations Low	Field Two Plots
Below Two Standard Deviations	

Sample	total glucan	struct glucan	soluble glucan	xylan	lignin	protein	ara-binan	structinorg	Plot #	Hybrid/ Inbred Designation	Planting Density Hi=3, Med=2, Low=1	Irrigation (in./week)
2868-066	44.0	37.8	6.2	22.0	18.5	2.1	3.0	1.4	1	B73 x Mo17	1	0
2868-091	42.7	35.9	6.8	20.5	17.2	3.0	2.7	3.5	2	B73x Mo17	1	0
2868-100	41.1	34.2	6.9	19.6	15.7	3.9	2.5	4.9	3	B73 x Mo17	3	0
2868-076	42.0	35.4	6.6	20.2	16.9	3.3	2.8	3.8	4	B73 x Mo17	3	0
2868-061	43.4	37.6	5.8	20.6	18.1	2.8	2.3	2.0	5	B73 x Mo 17	1	1.5"
2868-094	42.1	35.5	6.6	20.7	16.3	3.1	2.8	3.9	6	B73 x Mo17	1	1.5"
2868-080	40.1	33.0	7.1	19.2	15.9	4.4	2.6	5.3	7	B73 x Mo17	3	1.5"
2868-089	38.8	32.1	6.6	18.7	15.8	5.2	2.7	5.9	8	B73 x Mo17	3	1.5"
2868-086	42.4	35.8	6.7	22.1	16.4	2.7	2.9	3.4	9	Pioneer 33P67	1	0

Sample	total glucan	struct glucan	soluble glucan	xylan	lignin	protein	ara-binan	structinorg	Plot #	Hybrid/ Inbred Designation	Planting Density Hi=3, Med=2, Low=1	Irrigation inch./week
2868-087	42.6	36.1	6.5	21.6	16.2	2.4	2.9	4.3	10	Pioneer 33P67	1	0
2868-075	43.6	37.5	6.0	21.1	17.6	2.2	2.5	3.2	11	Pioneer 33P67	3	0
2868-062	42.5	35.7	6.8	21.0	16.1	2.6	2.6	5.0	12	Pioneer 33P67	3	0
2868-073	42.0	34.6	7.4	22.1	15.3	3.4	2.5	3.8	13	Pioneer 33P67	1	1.5"
2868-081	41.9	34.4	7.6	21.0	14.7	3.5	2.5	5.1	14	Pioneer 33P67	1	1.5"
2868-059	43.1	36.1	6.9	22.3	16.5	2.7	2.4	3.3	15	Pioneer 33P67	3	1.5"
2868-095	42.7	35.6	7.1	22.3	16.2	2.8	2.6	3.7	16	Pioneer 33P67	3	1.5"
2798-069	41.7	33.2	8.6	20.4	15.1	3.1	2.5	5.9	17	Tehua	unknown	1.5"
2868-070	50.3	30.7	19.5	14.5	12.2	4.5	-1.1	4.7	18	Teosinte	unknown	1.5"
2868-064	40.7	33.0	7.7	20.8	15.3	3.8	2.9	4.9	19	Cornbelt x Brazilian pop.	unknown	1.5"
2868-079	42.6	35.4	7.2	20.4	16.0	3.1	2.5	4.2	20	Cornbelt x Mexican pop.	unknown	1.5"
2868-071	40.8	33.5	7.2	21.0	16.1	3.7	2.8	4.7	21	Cornbelt2 x Teosinte	unknown	1.5"
2868-063	42.0	33.6	8.4	20.3	14.7	3.6	2.5	5.2	22	Early cornbelt pop.	unknown	1.5"

Sample	total glucan	struct glucan	soluble glucan	xylan	lignin	protein	ara-binan	structinorg	Plot #	Hybrid/ Inbred Designation	Planting Density Hi=3, Med=2, Low=1	Irrigation inch./week
2868-099	43.5	35.1	8.3	21.0	14.8	2.9	2.3	3.9	23	W Synthetic	unknown	1.5"
2868-068	40.1	31.4	8.7	19.5	14.8	4.8	2.4	5.9	24	NS(RFS) C9	unknown	1.5"
2868-088	41.7	31.7	10.0	20.1	14.2	4.3	2.2	5.1	25	NB(SI) C9	unknown	1.5"
2868-074	40.6	32.1	8.5	20.7	14.8	4.0	2.6	5.7	26	Midland (S)	unknown	1.5"
2868-085	40.7	33.4	7.3	19.5	15.3	4.0	2.5	5.8	27	Leaming (s) C5	unknown	1.5"
2868-084	41.2	33.1	8.1	20.9	14.4	3.4	3.0	5.4	28	Hoegemeyer 2641	unknown	1.5"
2868-092	40.8	33.2	7.5	22.5	15.1	3.2	2.4	4.8	29	Hoegemeyer 2641	unknown	1.5"
2868-096	40.5	32.1	8.4	19.1	14.8	4.7	2.0	6.0	31	CHIS775: N1912)-14	unknown	1.5"
2868-077	41.8	33.3	8.5	18.7	16.2	4.5	1.7	5.5	32	CHIS775: N1912) -14	unknown	1.5"
2868-060	40.3	32.2	8.1	21.3	15.1	4.0	2.9	5.1	33	ARO30506: N09)-12	unknown	1.5"
2868-093	40.8	33.8	6.9	19.8	16.8	4.1	2.4	5.1	34	AR030506: N09)-12	unknown	1.5"
2868-065	40.2	33.2	7.0	20.9	15.4	4.2	2.6	5.0	35	FS8A: S09)-6	unknown	1.5"
2868-090	40.8	34.2	6.6	22.1	16.6	3.5	3.0	3.7	36	FS8A: S09)-6	unknown	1.5"

Sample	total glucan	struct glucan	soluble glucan	xylan	lignin	protein	ara-binan	structinorg	Plot #	Hybrid/ Inbred Designation	Planting Density Hi=3, Med=2, Low=1	Irrigation inch./week
2868-057	39.0	30.9	8.1	18.3	14.5	5.1	2.4	7.4	37	DREP150:N2012)-24	unknown	1.5"
2868-058	38.7	30.7	7.9	19.3	14.6	5.3	2.6	6.8	38	DREP 150: N2012)-24	unknown	1.5"
2868-082	40.9	33.8	7.1	19.7	15.5	3.7	2.7	5.1	39	CHIS740: S1411a)	unknown	1.5"
2868-098	40.5	33.0	7.5	20.8	14.5	3.8	3.1	4.9	40	CHIS740: S1411a)-7	unknown	1.5"
2868-083	40.0	32.5	7.5	18.9	15.5	4.5	2.6	5.3	41	B73	unknown	1.5"
2868-078	39.4	32.1	7.3	20.6	16.1	4.4	3.1	4.0	42	CHIS 740: S1411a)	unknown	1.5"
2868-097	39.9	32.5	7.3	22.7	15.5	3.7	3.4	3.9	43	Mo17	unknown	1.5"
2868-072	39.8	32.5	7.3	22.4	15.8	3.8	3.4	3.9	44	Mo17	unknown	1.5"
2798-071	44.2	30.9	13.3	20.4	12.9	3.6	1.3	5.2		33P67	3	1.5"
2798-061	42.4	29.3	13.1	19.7	11.7	4.4	1.7	7.2		33P67	1	1.5"
2798-060	43.2	30.3	13.0	20.9	12.5	3.8	1.9	5.6		33P67	2	1.5"
2798-072	45.1	30.4	14.7	20.0	12.3	3.7	1.3	5.0		33P67	1	1.5"
2798-062	45.7	31.0	14.6	18.7	11.6	3.6	0.8	6.0		33P67	2	1.5"

Sample	total glucan	struct glucan	soluble glucan	xylan	lignin	protein	ara-binan	structinorg	Plot #	Hybrid/ Inbred Designation	Planting Density Hi=3, Med=2, Low=1	Irrigation inch./week
2798-067	42.2	30.1	12.1	21.6	12.6	3.8	2.0	6.0		33P67	3	1.5"
2798-074	45.3	30.9	14.4	20.0	11.6	3.6	1.1	5.5		33P67	2	1.5"
2868-073	44.6	31.8	12.8	20.7	13.0	3.3	1.2	5.4		33P67	3	1.5"
2798-070	45.1	29.6	15.5	18.7	11.5	4.1	0.9	5.8		33P67	1	1.5"
2798-068	40.6	31.6	9.0	21.1	14.5	3.7	2.8	6.0		B73/mo17	1	1.5"
2798-065	41.8	33.5	8.3	20.6	14.7	3.0	2.5	6.1		B73/mo17	2	1.5"
2798-059	41.1	32.4	8.7	20.7	14.9	3.5	2.6	6.2		B73/mo17	3	1.5"
2798-075	40.7	31.7	9.1	20.2	13.8	3.8	2.4	7.2		B73xMo17	1	1.5"
2798-069	41.7	33.2	8.6	20.4	15.1	3.1	2.5	5.9		B73xmo17	3	1.5"
2798-064	41.1	32.9	8.2	19.9	14.8	3.5	2.3	6.5		B73xmo17	2	1.5"
2798-063	41.0	32.5	8.5	20.5	14.9	3.6	2.5	6.0		B73xmo17	3	1.5"
2798-066	41.6	33.9	7.7	19.9	15.4	3.2	2.2	6.1		B73xmo17	3	1.5"
2891-069	41.0	31.7	9.4	19.9	14.0	3.9	2.3	6.7		B73xMo17	1	1.5"

TABLE 2. Summary of compositional data for each of 12 predicted constituents.

	Maximum	Minimum	Range	Average
total glucan	50.3	38.7	11.6	41.8
structural glucan	37.8	29.3	8.4	33.1
soluble sugars	19.5	5.8	13.8	8.7
xylan	22.7	14.5	8.2	20.4
lignin	18.5	11.5	6.9	15.0
structural inorganic	7.4	1.4	6.0	5.1
protein	5.3	2.1	3.3	3.7
arabinan	3.4	-1.1	4.5	2.4
acetyl	3.0	0.9	2.1	2.3
uronic acids	3.5	1.4	2.1	2.8
galactan	2.1	-0.4	2.5	1.6
mannan	1.7	0.7	1.0	0.9
soil	1.5	1.2	0.3	1.4
Global H	2.6	0.7	1.9	1.3
Neighbor H	1.5	0.2	1.3	0.8
Mass Closure	101.1	90.0	11.1	97.4

TABLE 3. Difference in composition between Plot 2A and Plot 2B, fractions of the same plot of corn representing the same genetic line, field/growing conditions, and harvest.

Scanning date	June 25th	July 2nd	July 2nd	June 25th	July 2nd	July 2nd	Standard Deviation	Standard Deviation	Standard Deviation
Plot	Plot 2A	Plot 2A	Plot 2A	Plot 2B	Plot 2B	Plot 2B			
Sample #	2868-091	2868-091	2868-091	2868-091	2868-091	2868-091	June 25th	Plot 2A(all)	Plot 2B(all)
total glucan	45.03	44.63	44.68	40.31	39.95	39.88	3.34	0.22	0.23
structural glucan	38.90	38.45	38.49	32.81	32.71	32.24	4.30	0.25	0.31
xylan	22.15	22.02	21.75	18.88	19.21	18.99	2.31	0.21	0.17
lignin	18.62	18.42	18.89	15.69	15.97	15.22	2.07	0.24	0.38
protein	1.65	1.81	1.92	4.36	4.50	4.50	1.92	0.14	0.08
acetyl	2.59	2.73	2.73	2.58	2.53	2.58	0.01	0.08	0.03
uronic acids	3.35	3.36	3.29	2.68	2.70	2.67	0.47	0.04	0.02
galactan	1.85	1.89	1.86	1.84	1.94	1.89	0.01	0.02	0.05
arabinan	2.75	2.89	2.80	2.73	2.81	2.84	0.01	0.07	0.06
mannan	0.82	0.82	0.82	0.75	0.77	0.78	0.05	0.00	0.01
structural inorg	1.50	1.45	1.22	5.43	5.06	5.62	2.78	0.15	0.28
soil	1.28	1.26	1.27	1.36	1.34	1.33	0.05	0.01	0.01

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Plot 2A **Plot 2B**

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TABLE 4. Total Square Analysis Example. (Total Glucan, Plots 1-16)

Total Glucan	Variety	Planting Density	Irrigation	VD	VI	DI	VDI
44.0	1	-1	-1	-1	-1	1	1
42.7	1	-1	-1	-1	-1	1	1
41.1	1	1	-1	1	-1	-1	-1
42.0	1	1	-1	1	-1	-1	-1
43.4	1	-1	1	-1	1	-1	-1
42.1	1	-1	1	-1	1	-1	-1
40.1	1	1	1	1	1	1	1
38.8	1	1	1	1	1	1	1
42.4	-1	-1	-1	1	1	1	-1
42.6	-1	-1	-1	1	1	1	-1
43.6	-1	1	-1	-1	1	-1	1
42.5	-1	1	-1	-1	1	-1	1
42.0	-1	-1	1	1	-1	-1	1
41.9	-1	-1	1	1	-1	-1	1
43.1	-1	1	1	-1	-1	1	-1
42.7	-1	1	1	-1	-1	1	-1
SUM	0	0	0	0	0	0	0
plus	41.8	41.3	41.7	41.6	42.5	42.0	41.9
minus	42.6	42.9	42.5	42.8	41.9	42.3	42.5
effect	0.9	1.6	0.8	1.1	0.6	0.2	0.6

KEY
No Irrigation = -1
Irrigation = 1
High Planting Density = 1
Low Planting Density = -1
B73xMo17 = 1
PIONEER 33P67 = -1

TABLE 5. Chi-square analysis of *Teosinte parviglumis* against 61 samples. Column one represents chi-square of all 8 significantly varying constituents, while column two shows the chi-square results calculated on a soluble sugar free basis.

	Chi-Square Analysis		
Sample #	Soluble Sugar	Without Soluble Sugar	
2798-069	0.003	0.20	*teosinte p.*
2868-086	0.97	1.00	Field One Pioneer 33P67
2868-087	0.98	1.00	
2868-075	0.89	1.00	
2868-062	1.00	1.00	
2868-073	1.00	1.00	
2868-081	1.00	1.00	
2868-059	0.97	1.00	
2868-095	0.99	1.00	
2798-071	0.84	1.00	Field Two Pioneer 33P67
2798-061	0.70	0.99	
2798-060	0.89	1.00	
2798-072	0.60	1.00	
2798-062	0.49	0.96	
2798-067	0.94	1.00	
2798-074	0.60	0.99	
2868-073	0.89	1.00	
2798-070	0.36	0.97	

Figures

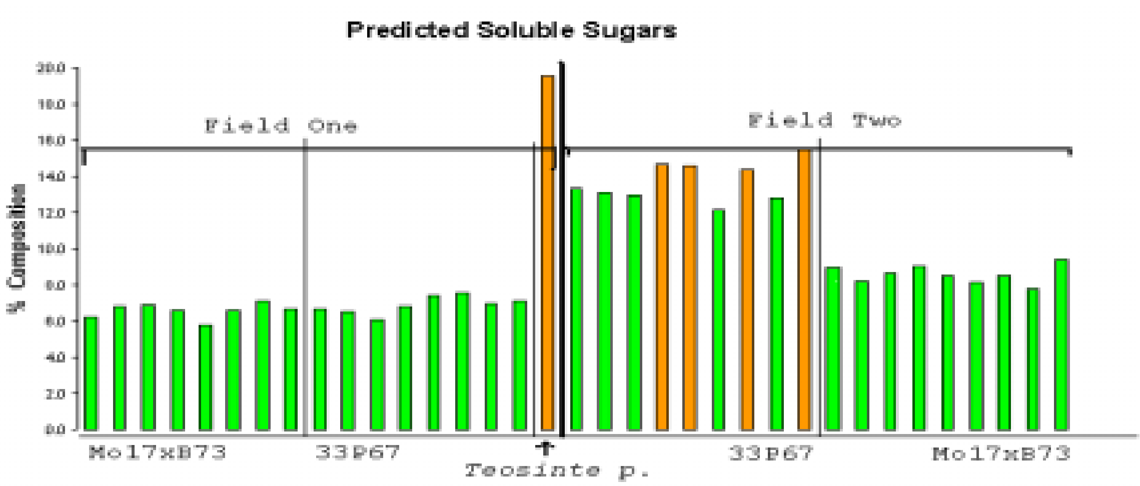

FIGURE. 1. Noticeable variation in soluble sugar content in identical lines 33P67 and outstanding soluble sugar content of *Teosinte parviglumis.*

FIGURE. 2. Comparison of composition of 60 *Zea mays* samples and *Teosinte parviglumis*.